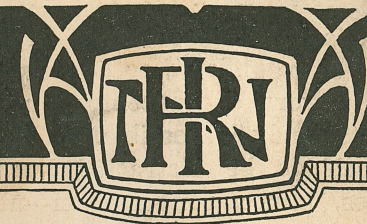




NATIONAL RADIO INSTITUTE

Certified Radio-Trician's Course

(REG. U. S. PAT. OFF.)



**GENERATION
OF
ELECTRICITY**

No. 3FR

Originators of Home Study Radio Courses
ESTABLISHED 1914
Washington, D. C.

FOREWORD

In this lesson we are going to begin to "hit our stride." We have completed what may be considered the introduction to our Radio studies. We have gotten into the proper frame of mind to tackle problems more or less technical.

Our work is naturally going to gradually become a little more difficult, so *be prepared*. Develop your powers of concentration. Have a quiet place to study if possible. If not, do not allow yourself to be distracted by *anything*. Street noises, music, conversation—all can be *tuned out* so you won't be conscious of them. Learn to work along steadily without allowing yourself to be interrupted. Work hard—rest hard—play hard. Whatever you are doing, do it well. Concentrate on the job in hand no matter what it is.

J. E. SMITH.

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NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

GENERATION OF ELECTRICITY

The term "generation of electricity" is, in a way, misleading. Electricity is a form of energy—electrical energy—and therefore cannot be *created* or *produced* by man. In other words, *electrical energy* cannot be generated without the expenditure of some other kind of energy. Of course, we continually talk about batteries and generators producing electricity. This is convenient, but you must know the truth back of this convenient statement, and that is, that a cell, battery or generator does not produce electricity. They are merely devices used for converting some other form of energy into electrical energy. A cell or battery is a device which transforms *chemical energy* into *electrical energy*, a generator is a machine whereby *mechanical energy* can be transformed into *electrical energy*.

STATIC AND DYNAMIC ELECTRICITY

Electricity is found in two forms; in one it exists as a charge upon a body, and is known as *static electricity*, while in the other form it consists of a moving current along a wire, known as *dynamic electricity*. We therefore have: Electrostatic electricity, that branch of the science which treats with electricity at rest.

Electrodynamic electricity, that branch of the science which treats with electricity in motion.

ELECTROSTATIC CHARGES

Electrostatic charges, or electric charges as they are often called, may be produced by rubbing briskly together a glass rod with a piece of silk, or by rubbing a stick of sealing wax with silk. The rubbing operation causes the glass or sealing wax in either case to be charged (electrified). Charges generated in this manner are called frictional electricity. We say that friction produces electricity, which is a convenient statement if not absolutely true. What we mean is that friction "electrifies" certain objects which in turn under certain conditions lose their charges and the result will be a flow of electrons.

If small pieces of tissue paper are brought near to the charged glass rod, it will be found that they will be attracted to it. In fact, they will jump up to the glass rod. Similarly, a stick of sealing wax rubbed with silk will attract small pieces of tissue paper. Should a stick of sealing wax "charged" be suspended in balance by a silk thread and the charged glass rod brought near to it, the sealing wax will be attracted by the glass rod. See Fig. 1(A). Two charged bodies may attract each other.

Instead of a glass rod, a rod of charged sealing wax is brought near the suspended stick of sealing wax. With this arrangement, we will find the suspended sealing wax stick is thrust away. See Fig. 1(B).

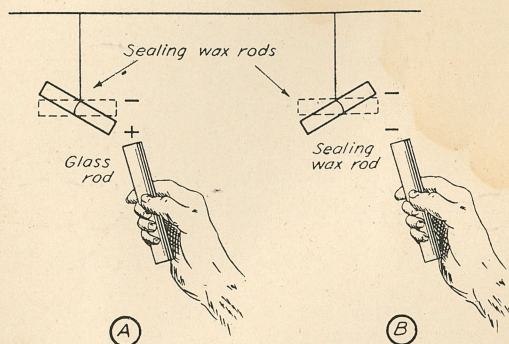


Fig. 1

Two charged bodies may repel each other. In this case, both sticks of sealing wax obviously contain the same kind of charge, from which the following laws apply to electrostatic charges.

1. *Like charged bodies repel each other.* (See Fig. 2.)

2. *Unlike charged bodies attract each other.* (See Fig. 3.)

This action demonstrates that there are two kinds of electric charges, to which the names positive (+) and negative (-) have been applied.

ELECTRON THEORY APPLIED TO CHARGES

The charges on bodies and many other electrical phenomena may be explained by the electron theory.

An atom is the smallest part into which matter may be divided by chemical means. An electron is a minute particle of negative electricity, and represents the smallest known particle of matter. Normally an atom has enough electrons col-

lected around it so that its positive charge is balanced or neutralized and it exerts no influence on its surroundings. A body which is positively charged has a deficiency of electrons, and tries to attract to it any electrons that may come near to it. A body which is negatively charged has a surplus of electrons and, therefore, has a tendency to repel or push away any excess electrons that may be within its neighborhood.

Man has put the electron to work and by making it perform has given us the marvels of the present age, among them Radio.

Remember when the electrons are at rest we merely have an electrical force or static electricity, as it is commonly known. When electrons move, we have a manifestation of magnetism. In the latter case, however, both conditions exist at the same

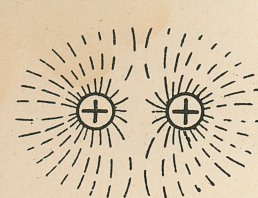


Fig. 2—Repulsion of like charges.

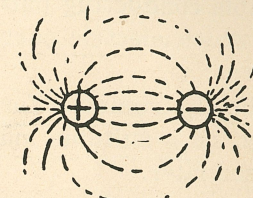


Fig. 3—Attraction of unlike charges.

time but we usually forget the static electricity and think only of the presence of magnetism because it is by far the most important.

The body with the negative charge will try to move toward a positively charged body, due to the laws that unlike charges attract. The space surrounding a charged body constitutes an electric field and another charged body in this field has a tendency to move away if it has a like charge, or closer, if it has an unlike charge.

From the above paragraphs, it can be understood that when we rub a glass rod with silk we deprive the glass rod of certain particles of electricity "electrons" which were taken up by the silk. In the case of the sealing wax, the silk cloth lost the electrons appearing on the wax. From this, we learn that electrons have no liking for one another and repel each other whenever in one another's presence.

DYNAMIC ELECTRICITY

An electric current is a flow of electricity and manifests its presence by the magnetic or heating effects it produces. The exact nature of an electric current is rather speculative, but according to the electron theory it is considered that electrons in motion constitute an electric current.

The electricity that flows along the electric light wires in your home or in your radio receiver is called *dynamic* or *current* electricity. When you see an electric light, a door bell, radio transmitter or receiver or other electrical devices that we use today, always remember that they are operated by dynamic electricity.

To generate electrical energy, a current must be forced through a circuit which means that there must be developed an electric pressure, difference of potential, e.m.f. or voltage; and a suitable conducting path (complete circuit) must be provided along which electric current can be circulated by this electric pressure.

The electromotive force may be produced by an electric cell, battery, or a suitable machine, several types of which will be discussed later.

According to the electron theory, it may be considered that a conducting wire is made up of many atoms with their attendant electrons moving about in a hit-or-miss manner at ordinary temperatures. If we make these electrons move in an orderly fashion in one direction, we will have an electric current. For, after all, electric current is nothing but a flow of electrons through a complete conducting circuit.

This action may be accomplished by the familiar electric cell, batteries or an electrical generator. The cell and the generator merely produce the necessary electrical force to move the electrons through the wire in an orderly fashion. Electrons, therefore, are not made; they exist in the copper wire as free electrons and the larger the wire in diameter, the more electrons exist to move when our generator produces that electrical force to send them on their way. Their direction is always from negative to the positive end of the conductor. It should be remembered that only the electrons travel in conductors. The atoms do not travel. If this were not so, the metals of which the various parts of an electric circuit are composed would mingle.

THERMOELECTRICITY

Electrical energy can be obtained from heat. If a copper and an iron wire are joined to form a complete circuit and heat is applied to one of the joints, an electrical current will be set up in the circuit. The current, however, will be very small so that electricity from heat is not commercially practical. The principle does have a practical use for electrical measuring of radio currents, such as the thermo-ammeter (the heat ammeter) in which a very small current produced by heating two different metals is sent through an ordinary meter.

ELECTRICITY BY CHEMICAL ACTION

Batteries used for converting chemical energy into electrical energy are far more important than most people realize. Because of the great publicity given to A.C. Radio sets in recent years, many people have the idea that batteries are out of date,

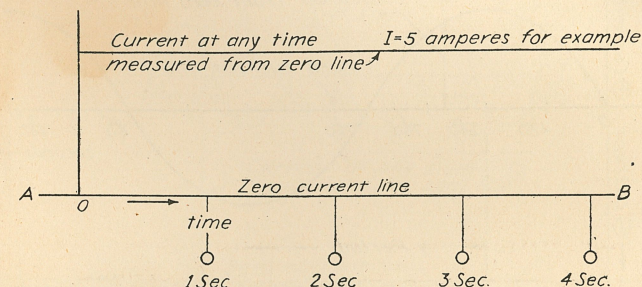


Fig. 4

that they belong to a past age, and that one can be an Expert Radio-Trician without knowing anything about the conversion of chemical energy into electrical energy.

You probably might know that this is far from being true. Aircraft Radio, Marine Radio, Broadcasting Radio, Television Transmitters and Receivers, Public Address Systems, etc., depend to a certain extent on battery power. Besides, batteries furnish power for the automobile and pleasure boat radio which is becoming more popular all the time. Batteries are frequently used in sound picture studios and in the projection booth. Thousands of homes in some towns, rural communities and on farms not wired for A.C. or D.C. depend on batteries.

Batteries will always be used in the laboratory and at the Radio-Trician's work bench.

Batteries generate e.m.f that is continuous and unchanging in strength.

The electrons flow in equal and definite amounts each interval (second of time) along a given section of the wire (conductor). Figure 4 shows this expressed in graph form. Notice that "line" is straight and parallel to the zero line A B.

If we consider the current to be 5 amperes (Fig. 4), this means the current is 5 amperes steadily and continually.

Most house wiring systems supply alternating (A.C.) current. Remember that the electrons flow first in one direction in the conductor, then in the other direction. Figure 5 shows this reversal of electron flow in graph form and shows the value of the current at any particular instant.

Do not confuse this method of expressing alternating current with wave motion. The wave like curve is used merely to picture the different values of alternating current—everything above the zero line represents electron flow in one direction—

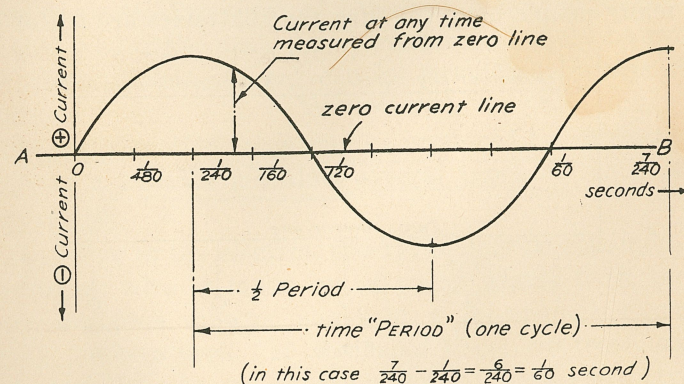


Fig. 5

below the zero line represents electron flow in the opposite direction.

The amount of current flow at any particular instant is measured from the zero line.

The crest of the wave curve represents maximum current flowing in one direction, the trough represents maximum current flowing in the opposite direction. The time it takes for the current to go from one maximum to the next maximum above the line (in the same direction) is referred to as the period (period of time) and in ordinary house current, this is one-sixtieth of a second. This is also referred to as a *cycle* of current because the current has started from zero, increased to maximum, decreased to zero, reversed its direction, reached maximum in the opposite direction and again returned to zero.

The number of cycles the current makes in one second is referred to as the *frequency*, and the frequency of the house current referred to above is 60 cycles per second. We call it a 60-cycle current.

Another form of current which enters largely into Radio is pulsating direct current which can be considered as a combination of A.C. and D.C. currents. Pulsating current flows always in the same direction but its strength is not steady—it increases and decreases periodically.

It is this type of D.C. current that we get from the rectifying tube in "B" eliminators before it is smoothed out with filters used in eliminators. Figure 6 shows how a pulsating current may be represented. Note that the curve is always above the zero line—meaning that the current moves only in one direction. The wave form of the curve shows that the current pulsates, its

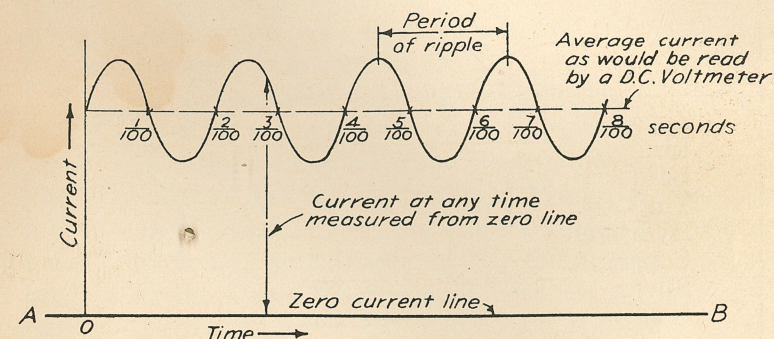


Fig. 6

strength decreasing and increasing. It has all the appearance of a pure D.C. current as in Figure 4 combined with a weak A.C. current. The A.C. portion is referred to as the "ripple."

We shall meet pulsating direct current frequently throughout our Radio studies. Besides being in our D.C. power socket and our A, B, and C supplies, it is present in vacuum tubes, audio transformers, loud speakers. It is one of the chief jobs of a Radio receiver to separate and combine the A.C. and the D.C. parts of pulsating current and use only the one needed.

PRIMARY BATTERIES

Batteries, as we know them, are made up of a number of single chemical cells. Strictly speaking, a single cell is not a battery—two or more connected together form a battery of cells.

The familiar dry cell is not correctly called a battery, but if two or more are connected together to form a source of electrical energy, we have a battery. The dry cell is known as a primary cell to distinguish it from the storage battery which is made up of secondary cells. *The main difference between primary and secondary cells is that the secondary cells can be renewed by passing an electrical current through them—primary cells cannot be recharged by a current flow. When a dry cell is dead, it is thrown away.*

The principle of the so-called dry cell is practically the same as that used in the old-fashioned wet cell which was in common use 15 or 20 years ago as a producer of current for ringing door bells and for laboratory work. This simplest of

TABLE NO. I

Material		Potential above zinc
— Zinc	—	0 Volts
Iron	—	.36 "
Lead	—	.71 "
Tin	—	
Hydrogen	—	.36 "
Copper	—	1.03 "
Silver	—	1.44 "
Gold	—	
+ Carbon	—	1.74 "

chemical cells is somewhat easier to study than the more complicated modern dry cell, so let us see what we can learn from a study of this old wet cell.

It consisted primarily of two different metals, zinc and copper (the electrodes) in an acid solution (the electrolyte) composed of one part of sulphuric acid in four parts of water. If two dissimilar metals are placed in a diluted acid solution, and the cell thus made is connected to an external circuit, electricity will flow through the circuit. The action of an electric cell is one of the most interesting of electrical and chemical phenomena. It starts when the sulphuric acid is poured into the water.

Volta, an Italian physicist, was the first man to discover that electrical pressure (e.m.f.) was developed between two un-

like metals placed in contact with certain liquids (acids and alkalis). He discovered from experiment that all metals bear a certain relationship to one another, that various metals in a cell arrangement produce different voltages.

If you want to experiment, take a copper penny and a silver dime, and lay them on a piece of moist paper. If the two terminals of a pair of phones are placed one on the copper penny and the other on the silver dime, a click will be heard in the phones each time the contact is made or broken. This is proof that an electromotive force was created. If you substitute a zinc disc for the copper penny, a louder click will be heard showing that a larger e.m.f. was produced. From this we can also gather that the copper is more positive than the zinc.

Table No. I shows the different electrical relationships existing between metals.

Zinc is used as a standard, the others are considered as positive to zinc—thus iron is more positive than zinc, lead is more positive than iron and so on.

You will notice from this table that carbon is 1.74 volts positive above zinc—consequently, we might suppose that a chemical cell with zinc and a carbon electrode would deliver 1.74 volts. The fact of the matter is that a hydrogen gas which is formed in a cell partially covers the carbon and this reduces the e.m.f. from 1.74 to 1.5 volts or 1½ volts. Zinc and copper according to the Table No. I should produce an e.m.f. of 1.03 volts, but this as you know can only be approximate.

A SIMPLE PRIMARY CELL

If we place in a glass jar a strip of zinc and a strip of copper or carbon and fill the jar with a weak solution of sulphuric acid (about 15 parts of water to one of chemically pure acid) and join by a metallic conductor the exposed terminals of these two strips we will find that the cell is capable of supplying a continuous flow of electricity along the conducting wire.

It will be observed as the current flows that the zinc strip wastes away in fact, the consumption of the zinc furnishes the electromotive force necessary to drive the current through the cell and through the external circuit. The chemical changes that take place within the cell, consisting of the zinc and copper strips immersed in the acid solution may be briefly described as follows: When the external circuit is complete and the current begins to flow, the acid attacks the surface of the zinc plate

and forms a compound known as sulphate of zinc. When the zinc is attacked by the acid, electrons are liberated which flow out of the zinc electrode and to the copper where it combines with hydrogen atoms to form a gas molecule of hydrogen. During the formation of this sulphate some of the hydrogen contained in the acid solution is liberated in the form of bubbles. Some of these bubbles rise to the surface of the liquid and escape into the surrounding air, but others cling to the copper plate which gradually becomes covered with a film of hydrogen. Since hydrogen is a non-conductor of electricity, the amount of surface of the copper strip in contact with the solution gradually decreases as the accumulation of hydrogen gas increases, there-

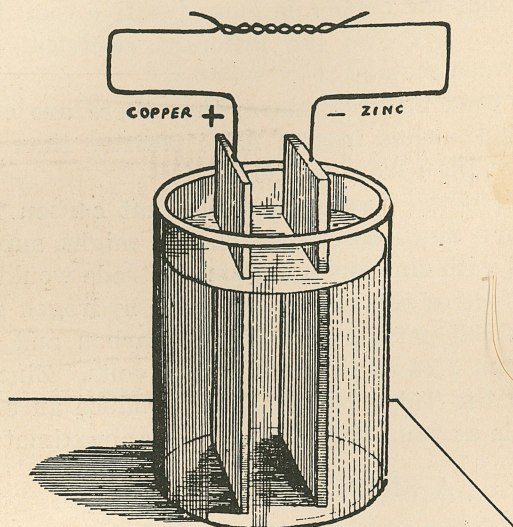


Fig. 7—Simple chemical cell.

fore the current output of the cell diminishes. Using an electrician's term the cell is now said to be "run down" or dead.

The so-called dry cell which is in use at the present time, works on the same principle. It is not really a "dry" cell, for the exciting solution is in paste form and if this paste were allowed to dry out the cell would be useless. The construction of an ordinary dry cell is as follows: A zinc cup both contains the material of which the cell is made and provides the negative electrode. A carbon electrode (positive) is placed in the center as a core, and the space about the carbon is filled with manganese dioxide and powdered carbon, this being separated from the zinc cup by a layer of sal-ammoniac paste held by porous blotting

paper. The peroxide of the manganese (manganese dioxide) is added to the electrolyte to lengthen the life of the cell by preventing the formation of hydrogen about the carbon electrode.

The paste is sealed into the cell and the carbon electrode is firmly held in place by wax or pitch. This also keeps the cell from drying out.

Ordinary dry cells are capable of producing an electromotive force (e.m.f.) of $1\frac{1}{2}$ volts. A "B" battery consists of a number of primary dry cells connected in series so that the voltage obtainable is the *sum of the voltages* of the individual cell. We shall learn more about this. Strictly speaking, a single cell should not be called a battery, the word battery meaning a number of cells connected together.

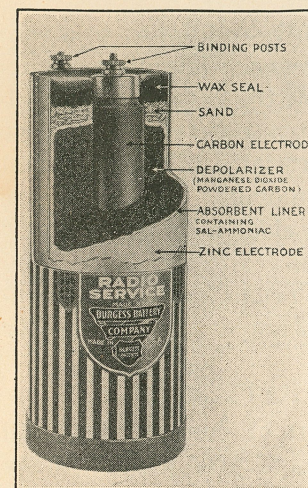


Fig. 8—Cut-away view showing construction of a dry cell.

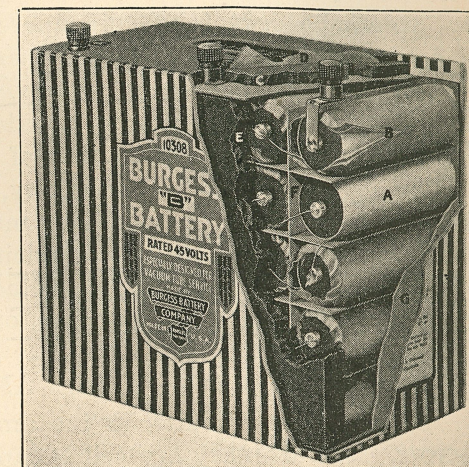


Fig. 9—Cut-away view showing construction of a 45-volt B battery.

The old-fashioned wet cells and dry cells that are used at the present time, are called primary cells to distinguish them from the type of cells used in storage batteries, which are called secondary cells. Primary cells cannot be recharged, secondary cells can be. When the chemicals in the primary cells become inactive, the cell is useless—when a secondary battery is run down or discharged, it can be renewed by passing an electric current through it. In other words the electrodes and electrolyte (solution) are of such materials that there can be no chemical action between them until after current has first been forced through them.

QUANTITY OF ELECTRICITY

Electricity is measured by its effects, or the work it does; the greater the effect, or the work done, the greater is the quantity of electricity.

If we have a closed circuit which has a resistance of one ohm and we apply to it an e.m.f. (pressure) of 1 volt, then 1 ampere will flow through the circuit. The coulomb is the commonly used unit of quantity or amount of electricity, just as the gallon is the commonly used unit of quantity or amount of liquids.

A coulomb of electricity, so it has been estimated, is about 16 million million million electrons, free and ready to move. Therefore an ampere is this amount of electrons moving in a wire past a definite section in one second.

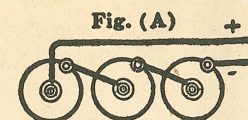
In other words, the term ampere has been applied to a rate of flow of a coulomb of electricity per second. Therefore a current of one ampere is a current flowing at the rate of a coulomb per second. It so happens in practical work we nearly always are interested in the rate of flow of electricity in amperes and seldom in the amount of electricity, coulombs. If an ampere flows in a circuit for 1 hour, how much electricity has passed? Q, the symbol for quantity of electricity, is $1 \times 60 \times 60$ or 3,600 coulombs. This is referred to by Radio-Tricians as an ampere-hour, meaning that 3,600 coulombs, or an ampere has flowed for 1 hour.

CONNECTING CELLS AND BATTERIES

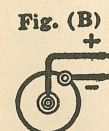
Dry cells are limited in the amount of current they will deliver. The ordinary dry cell is capable of producing with its e.m.f 25 amperes of current in an external circuit.

If a dry cell could deliver 25 amperes for 4 hours, its electrical capacity would be 25×4 or 100 ampere-hours. But suppose we want twice that capacity—we could arrange two dry cells as shown in Figure 10(D). If we wanted 3 times the capacity of 1 cell, we would arrange 3 cells as in (F) or as in (H) for 4 times the capacity. Four times the capacity of 1 cell would be $25 \times 4 \times 4$ which equals 400 ampere-hours. These are called a parallel arrangement (a parallel battery) and although we are increasing the capacity by adding more cells, the e.m.f. produced will always be the same as that of a single cell—1½ volts.

For many kinds of work 1½ volts is not enough. If we connect three dry cells in the manner shown in Fig. 10(A)—that

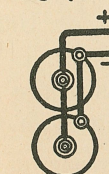


Series, 4.5 Volts



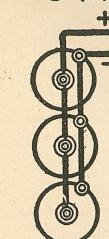
Single Cell
1.5 Volt

Fig. (D)



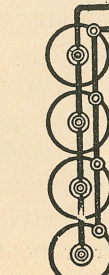
Parallel
1.5 Volt

Fig. (F)

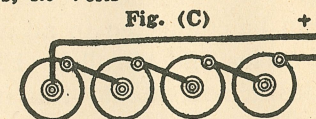


Parallel
1.5 Volt

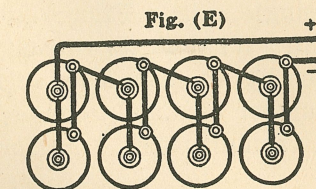
Fig. (H)



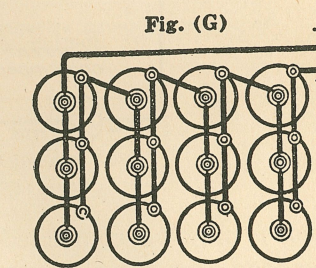
Parallel
1.5 Volt



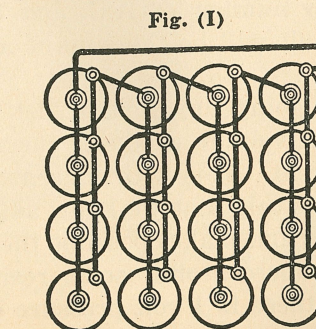
Series 6.0 Volts



Parallel Series, 6.0 Volts



Parallel Series, 6.0 Volts



Parallel Series, 6.0 Volts

Fig. 10

is with the connections going from the carbon terminal of one cell to the zinc terminal of the next, the total voltage will be three times as much as that of a single cell ($3 \times 1.5 = 4.5$ volts). This is a *series* arrangement (a series battery). However, the capacity of this arrangement is the same as the capacity of one single cell—only the voltage has increased.

Cells can be connected in an arrangement which is a combination of series and parallel. Figure 10(E) shows a simple parallel-series arrangement—this is equivalent to two batteries of 6 volts each connected in parallel. Figure 10(G) is equivalent to 4-6 volt batteries connected in parallel—and the capacity is that of 3 single cells. Figure 10(I) shows a parallel series arrangement. What is its capacity? 25×4 or 100 ampere-hours, driven by an electromotive force of 6 volts.

Any number of e.m.f. sources, dry cells, storage batteries, generators, vacuum tubes, transformers (things you will learn

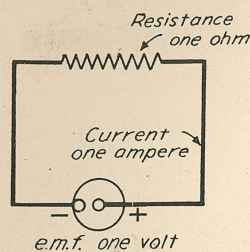


Fig. 11

all about soon) may be connected in parallel *providing* they supply *under load* (drawing current) equal voltages.

Any number of e.m.f. supplies may be connected in series. In fact, any number of A.C. and D.C. voltages may be added and the result will be the sum of all of them at any instant of time.

Before going any further, let us get very clearly in mind the fact that voltage produces current when a path is provided for the current. It is with current flow that we are vitally concerned. It is this that we know as electricity, it is current that works for us and makes possible the wonders of electricity.

All conductors offer some resistance to current flow in a circuit. If there is 1 volt pressure in a circuit and a current of 1 ampere is flowing, the resistance opposing the action of 1 volt is 1 ohm. See Fig. 11. Surely, if the resistance in ohms is greater, the e.m.f. will have less effect and the current will be lowered in value.

STORAGE BATTERIES

There are two general classes of storage batteries; the lead plate, sulphuric acid cell, such as the Exide, Willard, Philco, and the nickel, iron-alkali cells developed by Edison. The lead

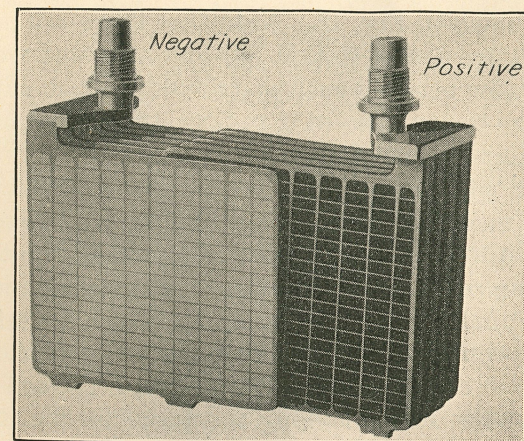


Fig. 12—Positive and negative group of plates of a storage battery.

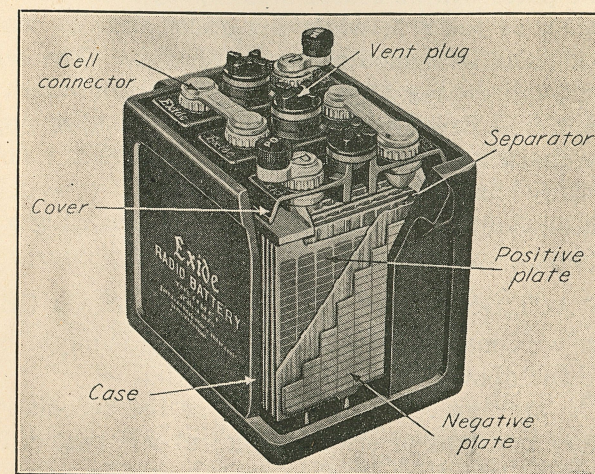


Fig. 13—Cut-away view of a storage battery showing details of construction of one cell and the connections to the other two cells.

plate type of storage battery is mostly used as a source of power therefore this type will be described first.

Storage batteries consist of two or more chemical cells in which the chemical action is reversible—that is, an electric

current passed through the cell restores the chemicals to an active condition so that they can supply an e.m.f.

There are ordinarily three cells in a 6-volt storage battery.

THE LEAD CELL

A typical storage battery with a cut-out section of one of the cells is shown in Fig. 13. Note that there are several positive and negative plates in this cell and a porous wood or hard rubber separator between each plate and a bottom support. The separators are so constructed that they will allow the electrolyte to pass through them readily.

The lead plates contain holes or grooves which are filled with a paste made of red lead or litharge. Alternate plates are connected to different terminals, those connected to the negative terminal being one more in number than those connected to the positive terminal. The plates are placed in a containing vessel and a 20 per cent. solution of sulphuric acid added. A current of electricity is then caused to flow through the cell for a number of hours, the result leaving the paste in one, the form of spongy lead. At the same time, the plate at which the current enters the cell is, converting the paste into lead peroxide. Finally, one plate will be coated with spongy lead, forming the negative plate of the cell, while the other plate is coated with lead peroxide and is termed the positive plate. The cell is now charged and will deliver a current for a certain length of time. This current will flow from the cell in a direction opposite to that of the charging current, the potential being 2.1 volts when the cell is fully charged.

A cell of the above construction is known as the "Exide" and is employed very extensively for radio purposes.

THE ACTION OCCURRING IN THE LEAD CELL

Before we consider the action of the cell it might be well to summarize the above. We have learned that—

1. The storage cell (also known as the secondary cell or accumulator) is a type of electro-chemical cell, that differs from the primary cell in that for renewal it merely needs to have current flow through it from an outside source.

2. By conversion of electrical energy into chemical energy, the storage cell forms a portable and convenient source of electrical energy which can be employed when any other source would be out of the question or where it is inconvenient to have generating plant running continuously.

3. The lead cell contains plates of lead, the positive plate being coated with lead peroxide and the negative with "spongy lead." These plates are immersed in a solution of sulphuric acid and water.

4. The electrolyte or solution of the lead cell is made of four parts pure water and one part pure sulphuric acid.

5. By "charging" a cell is meant the process of chemically changing the plates so that the cell will deliver a current, this being brought about by causing a current to flow through the cell for a time.

6. By "discharging" of a cell is meant the delivery of electrical energy by the cell to an external circuit.

When a cell is placed on discharge the current is produced by the combination of the sulphuric acid of the solution with the active material of the plates. The product of this combination is lead sulphate and water. The lead sulphate fills the pores of the active material, and the water is left in the solution, causing it to become thinner. The volume of sulphate formed by this combination is greater than the volume of sulphuric acid and lead which entered into the combination. The result of this is that as the discharge goes on, the sulphate which fills the pores in the plates prevents the action of the solution on the active material. Therefore the voltage will gradually drop as more and more sulphate is formed. The maximum voltage of a lead cell is ordinarily about 2.1 volts, while the lower limit is 1.75 volts. The voltage should never be allowed to drop below 1.75 volts, because after this point is reached the voltage falls off very rapidly, and possible damage to the plates may result.

In charging, direct current of greater voltage than the maximum potential of the storage battery is caused to flow through the cells in an opposite direction to that which the current takes when the cell is discharging.

The sole object of charging, then, is to drive the sulphate from the plates back into the solution, thus leaving spongy lead on the negative plate and lead peroxide on the positive.

Is a cell of this type properly called a "storage" cell? No, because electricity is not stored in it. When it is being charged, electrons are forced into it, but they leave it by the negative terminal. Electrons do not leave the circuit. No new electrons are put into the cell—it is the passage of the electrons in reverse direction that affects the cell chemically. Recharging therefore

consists of restoring the chemicals in the cell, discharging involves the breaking down of the active chemicals.

The degree of charge in a secondary cell can be ascertained by measuring the specific gravity of the electrolyte. As the cell discharges, more and more water is formed and the lighter the electrolyte becomes.

The device used to measure specific gravity is the "hydrometer." It is nothing more than a glass tube with a float inside it. The float has a graduated scale reading from 1.100 near the top to 1.300 near the bottom.

In testing a cell, a portion of the electrolyte is drawn into the glass tube, and the float rises in the liquid. (See Fig. 14.) If the liquid is heavy the float will rise farther out of the liquid than if it is light. The lighter the electrolyte, the more water is in it.

A hydrometer reading between 1.250 and 1.300 indicates that the cell is at least half charged. A reading of less than 1.150 indicates that electrolyte is almost all water, that no further discharge should be allowed, and that the cell should be put on charge.

THE EDISON BATTERY

While the lead type of storage cell is very common, another type of battery, the Edison Battery, has many advantages over the lead type which makes it particularly adapted to use on board ship. The Edison cell employs an alkaline electrolyte, a solution of potassium hydroxide, to which flake nickel is added, instead of the sulphuric acid solution used in the lead cell. The advantage of this electrolyte is that it has no appreciable wearing effect on the plates, and so the Edison cell will outlast many lead cells.

The electrodes of the Edison cell are more complex than the lead electrodes—the positive plate consists of tubes into which the active ingredients, nickelous hydroxide and flake nickel are packed, securely held in place on a steel grid (framework). The negative plate consists of a steel grid divided into compartments for the insertion of strips of perforated nickel-plated steel ribbons. The active materials are pure iron which has undergone several chemical processes, mixed with 6% of yellow oxide of mercury. This is placed in the perforations during the "formation" process.

The can of an Edison cell is steel, nickel-plated. Naturally cells of this sort are more costly than lead cells—and they are much bulkier because the Edison cell is capable of producing an e.m.f. of only little more than half that of the lead cell.

A. C. GENERATORS

While electricity from chemicals is of great importance in modern life, by far the most important and most widely used method of "producing" electricity is by means of *generators*, which involves the conversion of mechanical energy into elec-

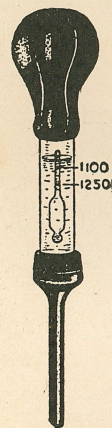


Fig. 14—A hydrometer used for determining the condition of a storage battery.

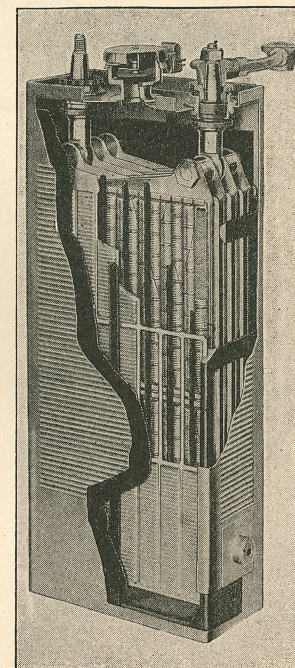


Fig. 15—Cut-away view of an assembled Edison cell.

trical energy. To supply the mechanical energy, steam engines are commonly used, and then the energy in coal goes through several conversions, finally resulting in the production of electricity.

The use of water power as the provider of mechanical energy for the production of electricity is getting to be very general—and in this case there is a conversion of water pressure, to mechanical force, to electric pressure (e.m.f.).

In this chapter, we shall study the principles of the generator, the machine which converts mechanical energy into electrical energy.

ELECTROMAGNETIC INDUCTION

This principle is of great commercial importance because on it depends the operation of electric generators in converting mechanical energy into electrical energy.

If two permanent magnets or electromagnets are placed near one another, with the North pole of one facing the South pole of the other and fastened in some manner so that the attraction between the two will not draw them together they will create a magnetic field in the intervening space that is composed of lines of force flowing from the North pole to the South pole.

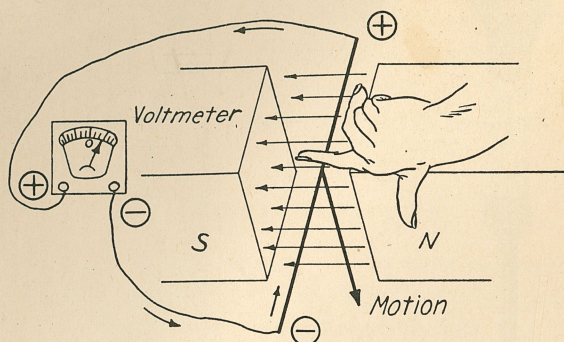


Fig. 16

If a wire is moved in that space between the electromagnets (through the magnetic field), an e.m.f. is induced in the wire. By experiment, we can study this action and learn some very interesting facts about generators (and motors).

In Figure 16 we have two permanent magnets, a milli-voltmeter (a device to measure small e.m.f.'s) and a length of wire, its ends connected to the voltmeter.

We pass a portion of the wire through the magnetic field, at right angles to the flux (lines of magnetic force). What has happened? The voltmeter shows that an e.m.f. had been generated. Now we bring the wire back through the flux—and the voltmeter again shows an e.m.f.—but the reading is on the opposite side of the zero mark. This can mean only one thing—that the e.m.f. direction has been reversed. Note that in Fig. 17

the voltmeter connection is reversed so that the needle will read up scale. This affords a method of determining the + and — terminals if the voltmeter is marked.

Let's try moving the wire parallel to the lines of force (flux). Nothing happens, there is no evidence of voltage at all—the needle of the voltmeter has not moved. Then we move the wire diagonally through the field—the voltmeter needle has moved—but not as far as when we cut the flux at right angles. There is an e.m.f. but a small one.

What conclusions can we draw from these experiments? Clearly the greatest e.m.f. is produced when the wire cuts the flux at right angles. At any other angle the e.m.f. is less. It gradually becomes less as the cutting becomes parallel to the flux lines.

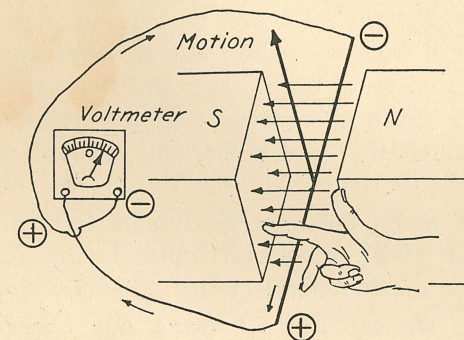


Fig. 17

Keeping these facts in mind, we can go on with our experiment and learn more about generators. We want to see what effect moving the wire through the flux at different speeds will have on the e.m.f. We move the wire at a certain speed (let us say at 10 ft. a second*) through the magnetic field at right angles to the lines of force. We note the reading. Let us say it reads 2. Then we move it twice as fast—we read 4. Moving it 3, 4, 5 times faster will cause a correspondingly higher voltmeter reading, 3×2 ; 4×2 ; 5×2 (6, 8, 10).

We can do the same thing, cutting the flux diagonally. Suppose that at the first speed the meter reads 1. Double the speed—the reading shows 2, etc.

*This does not mean that a wire must travel 10 ft. to have this speed (velocity). It means that if this wire was allowed to continue its travel for one second without going faster or slower it would cover 10 ft; 10 ft. per (for each) second.

But no matter how fast we move the wire *parallel* to the magnetic lines of force, we can't get a reading—no e.m.f. will be set up in the circuit.

If we substitute electromagnets with greater magnetic fields for the permanent magnet, we shall find that we can get much larger e.m.f.'s.

We can set up, in our imagination, a more complete experiment. We have 2 electromagnets; we place them so that the North pole of one faces the South pole of the other at a distance of about 2 inches. Then we get a piece of wood about an inch and a half square, a quarter of an inch thick. We mount this piece of wood on a *shaft* and place it so that we can make it rotate in the magnetic field of the electromagnets. We fasten a turn (loop) of wire to the edges of the wood and connect the two lead wires to two separate copper rings mounted on the shaft so they will turn with the piece of wood and loop of wire. They are insulated from each other and from the shaft. (This whole assembly is an *armature*—and the poles of the electromagnets are called the *field* poles, the lines of magnetic force between the poles is the *flux*.)

Contact is made between the rings (slip rings) and the external circuit (with a special voltmeter in it) by *brushes*, pieces of copper mesh (metal cloth) or small blocks of carbon.

With this, we can start making our observations of an elementary (simple) generator. The armature is rotated by means of a small crank handle (it can be made by bending a wire to the shape of a crank). Watch the meter—it shows a good strong e.m.f. at times and the needle is always moving, first on one side of the "zero" line, then on the other. The e.m.f. is reversing in direction all the time. Turn the armature more quickly—the needle will swing back and forth faster—and farther. The maximum e.m.f.'s are greater and the reversals (alternations) are more frequent.

We can determine by experimental observations why this e.m.f. should be alternately in one direction and then in the other. First, however, we must understand more completely, the results of our previous analysis. Apparently, the direction of the motion and the direction of the lines of force have a great deal to do with the direction of the voltage.

Let us use an ordinary voltmeter having two terminals marked "—" and "+." In the study of batteries, we recall that

the zinc negative and the copper positive terminals meant that the current flowed from "+" to the "—" terminal, outside of the conductor. The e.m.f. also pushed the current in the same direction. If we were to connect the above voltmeter to the battery, it would be essential that we connect the positive terminal of the voltmeter to the "+" of the battery and the negative terminal of the voltmeter to the "—" of the battery in order to have the voltmeter needle deflect to the right. In this case, the needle of the voltmeter would read up the scale and give us the correct voltage. Should we reverse the connection, the needle would read down the scale and injure the needle of the meter if we were not careful. When this happens, naturally the thing to do is to reverse the connections to the voltmeter. Then, a voltmeter of this kind, will enable us to determine the positive and negative of any e.m.f. source. The voltmeters in Figs. 21 and 22 are of a special make which will allow the needle to deflect to the left as well as to the right of its zero position.

Now, referring to Figs. 16 and 17 which shows lines of magnetic force existing between the North and South poles and in the direction from the North to the South pole. The wire which we are going to push through the magnetic field is connected to the voltmeter. By connecting it to the voltmeter correctly, that is, so that its needle reads to the right of zero, we may determine the + and — of the conductor and thereby determine the direction of the e.m.f. generated in the wire. Instead of pushing the wire downwards, as in Fig. 16, let us pull it upwards. Immediately, the voltmeter would read to the left of zero which will show us that the negative and positive terminals of the conductor are opposite to that when the motion is down. Consequently, if we reverse the connections as shown in Fig. 17, the needle will again read to the right. We must not overlook the fact that the e.m.f. is generated in that portion of the conductor which is cutting the lines of force. The balance of the conductor is nothing more than a carrier for the generated currents. It is particularly easy to remember this procedure but fortunately, we have what is known as Fleming's Right-hand Rule which is shown and applied in Figs. 16 and 17—first, set the thumb, index finger and middle finger at right angles to each other as shown. Then point the thumb in the direction of motion while the index finger points in the direction of the lines of force. The result will be that the middle finger points in the direction of the induced e.m.f.

Now let us consider the armature turning to the right or clockwise as it is more technically called (rotating in the direction of clock hands). Figure 18 shows an elementary generator having North and South poles and slip rings with a turn of wire A-B. We can consider sides A and B as two conductors connected in series. Let us direct our attention to conductor A. As shown, it is ready to pass in front of the South pole and in the position it is in, lines of force are not being cut because of that particular instant, the conductor is moving parallel to the lines of force. As conductor A passes through the center of the South pole, it is cutting the lines of force perpendicularly (at right angles) and at that point the induced e.m.f. will be the largest. Rotating still farther or to the position where B is, the voltage induced will again be zero. We can analyze conductor B in the same way.

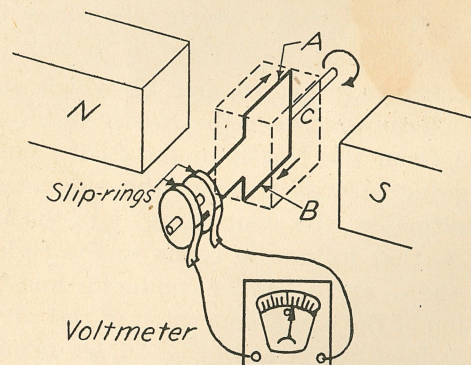


Fig. 18

In going from B to A it will cause a voltage to rise to a maximum and then to zero and its direction may be determined again by Fleming's Right-hand Rule. Note, however, that the two conductors which are connected in series have voltages in the same direction, that is, the + is connected to the — as we did in the battery when we wanted to add the e.m.f.'s together. Therefore, we say that the voltage generated in conductor A and conductor B add to form the voltage which is read on the voltmeter.

Now conductor A is ready to pass through the north field and according to Fleming's Right-hand Rule, the e.m.f. will be in the opposite direction. Likewise, the e.m.f. in conductor B will change with the result that the voltmeter will read down the scale provided we use the milli-voltmeter which reads zero in the

center and which indicates and measures voltages in either direction. This voltage is known as alternating current voltage and the current produced by an alternating current voltage is called "alternating current." Figure 19 shows what is known as the ideal alternating current voltage and it is known as the *sine wave* e.m.f. which is the goal of every A.C. generator designer.

How may we trace a sine wave so that we may use it as a standard for comparison? Let us assume that the maximum voltage produced is 10 volts. In other words, our maximum deflection of the meter from zero would be 10. Let us take a point as the center and draw horizontally a line divided into 10 equal portions and with a compass—an instrument to draw circles—draw a circle using this line as the radius. (Fig. 19.)

Through the center, draw a perpendicular line, dividing the outside of the circle (its circumference) into 4 parts. Again

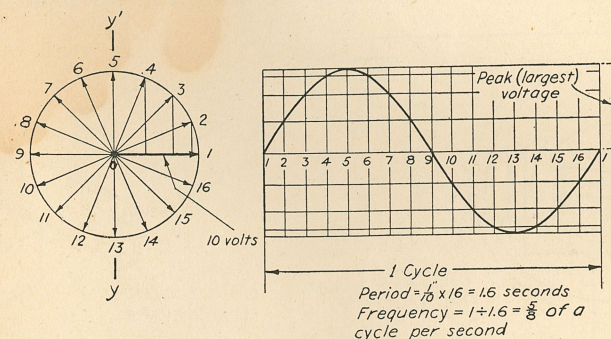


Fig. 19

with our compass let us divide this circumference into 4 parts and from these points, draw lines parallel to "y'-y."

Let us imagine that the point "O" is the armature shaft and the points 1, 2, 3, 4—up to 16 are the different positions that conductor A is in when the armature is turned around. At position 2, the amount of voltage generated will be represented by the length of the line between point 2 on the circle and the horizontal line. At point 3, the length of the line between 3 and the horizontal line and so forth for the various positions. At positions 1 and 9, the e.m.f. will be zero and they represent the positions of the conductor when moving parallel to the lines of force. Positions 5 and 13 represent the conductor A when in the center of the North and South poles. The voltages below the horizontal line represents the e.m.f. acting in one direction

and the line above the horizontal line represents the e.m.f. in the opposite direction.

Naturally, it takes the conductor a definite length of time to go from 1 to 2. Since the length 2 to 3 is the same as 1 to 2, it should take the same length of time. Let us assume it to be $1/10$ of a second. From point 1 on the horizontal line, let us lay off 16 equal distances and each of these divisions will represent $1/10$ of a second. At position 9, just as in position 1, the length is zero. At 10 we must naturally measure off below the line. Points 5 and 13 represent the maximum voltages. Now draw a line connecting all these points. The result is what is known as a sine curve and any A.C. voltage or A.C. current, the curve of which is like this sine curve, is called a sine A.C. voltage or sine A.C. current.

Alternating current machines, naturally, do not use permanent magnets and a single loop of wire for an armature as

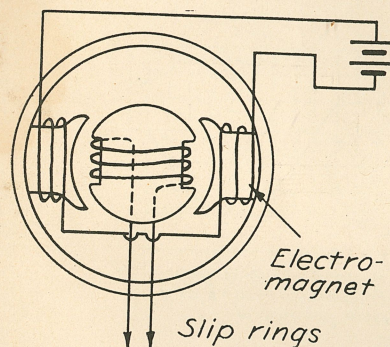


Fig. 20

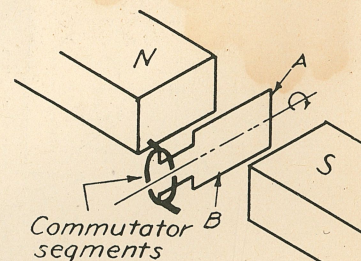


Fig. 21

shown in these elementary illustrations. They use two or more electromagnets, called field coils, the armature having an iron core, on which a number of wires are wound in the form of loops insulated from the core and from each other. (See Fig. 20.)

One end, or half, of every loop on the armature is connected to a collector ring, the other end, or half, to the other collector ring. When a loop revolves in the magnetic field from the field coils, one-half of it cuts down on lines of force while the other half is cutting up. Every half revolution the loop changes because the half that was cutting up is now cutting down, and the half that was cutting down is now cutting up. This causes the induced current to reverse its direction and flow to the other collector ring. Every loop on the armature experiences this and

so the induced current is alternating—changing its direction of flow at regular intervals—whenever the two halves of each loop reverse their direction of cutting lines of force. When an armature loop is at the point of changing the direction of the flow of the induced current in itself it is scarcely cutting any lines of force, consequently it is inducing no current. As the loop revolves it gradually cuts more and more lines of force until it reaches the densest portion and from the point gradually cuts fewer and fewer lines of force until it is at the point of again changing its direction; thence it gradually reaches its maximum, decreases to zero again, and changes its direction once more. Each complete operation is called a CYCLE.

Figure 20 shows a drawing of a small A.C. generator the field coils may be supplied by current delivered by a battery or a D.C. generator which we are now going to study.

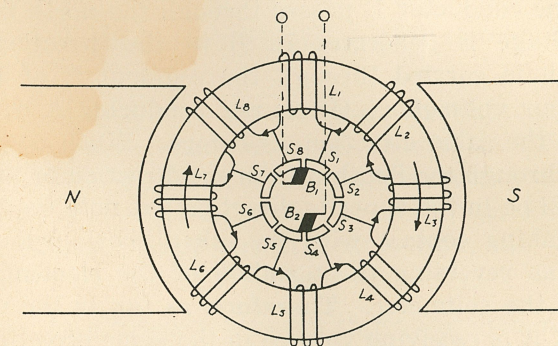


Fig. 22

D. C. GENERATORS

Before taking up the study of the production of direct current by mechanical means, it will be well to remember that all Radio receivers use direct current.

In modern receivers, direct current is obtained by "rectifying" (making over) alternating current into D.C. current. The only place in a Radio receiver where alternating current can be used as it comes from the light socket is in the vacuum tube filament circuits where electricity is used only for heating purposes. It is, therefore, essential that a Radio-Trician understand the principles of direct current and its production from alternating current, and especially those methods of producing D.C. (by D.C. generators) as used in all broadcasting transmitters, all

commercial transmitters, or, in fact, any Radio receiver or transmitter where exceptionally large direct currents are needed.

The elementary D. C. generator is quite like the A.C. generator. The only difference is that the slip rings are replaced by a different kind of current collecting device, called the "commutator." Figure 21 shows a drawing of a simple commutator. It is in two parts (segments), each insulated from the other and each connected to one end of the armature coil, just as the slip rings (or collector rings as they are sometimes called) were in the alternator. Should we connect such a generator to our original voltmeter, and turn the crank of the armature in a clockwise direction, we would find that the needle now reads to the right, returns to zero and then moves to the right again. For every complete revolution of the armature, the needle would move twice from the zero-position.

When the conductor B passes through the north field as in Fig. 21, voltage is generated in B in the direction of the arrow, which is carried through the segment C of the commutator to our voltmeter. Of course, conductor A will supply a voltage in the same direction as before. When conductor B now passes through the South pole in the direction of the arrow, the e.m.f. will be in the opposite direction but note that segment C is now making contact with the other brush, which is the same thing as reversing the terminal of the elementary A.C. generator to the voltmeter. Therefore, as far as the voltmeter is concerned, it is receiving voltage in the same direction. This reversing action takes place twice in one complete rotation of the armature. But our voltage, although acting in the same direction, is not a D.C. current. It is rather a pulsating current and a bad pulsating current at that.

This is exactly the kind of voltage that is generated by a vacuum tube B supply device and we might, if we wanted to, use the same apparatus (a filter) as is used in Radio receivers to smooth out the ripple of P.D.C. Such a device, however, can be used only where small e.m.f.'s are being generated. D.C. generators, you must not forget, are used where there are large demands for D.C. electricity.

Figure 22 shows a simple generator using an electromagnetic field and an armature made up of 8 conductors and using 8 segments. Such a D.C. generator will supply a D.C. voltage—graphically shown in Figure 6.

By using 50 to 150 commutator segments and armature conductors, the ripple can be very greatly diminished until it approaches very closely to a pure D.C. The electromagnetic field which requires D.C. current for its supply, may now derive its voltage from the generator itself, instead of from an external battery or generator and as shown in Fig. 20, the field is connected in parallel with the armature or *in shunt*, as it is most usually referred to.

Now that you have finished Lesson Three, lay down the text-book for a moment and review in your mind what you have read. Go over the lesson mentally as far as possible. Then take up the lesson again, and be sure you have not missed any of the important principles, particularly those which are most essential—they are the key to the whole lesson.

TEST QUESTIONS

Number your Answer Sheet No. 3FR and add your *Student Number*.

Never hold up one set of lesson answers until you have another set of lesson answers ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. State the difference between static and dynamic electricity.
2. Explain the action of like and unlike charges.
3. What are the two principal methods used to produce electric current?
4. A battery of three cells in series, each having an e.m.f. of 1.5 volts, what is the total voltage or e.m.f. of the battery?
5. Draw a diagram showing how three dry cells are connected in parallel.
6. What is the most important thing to consider when connecting dry cells in various ways?
7. Explain briefly the difference between a primary cell and a secondary cell.
8. What device is used to measure the specific gravity of an electrolyte?
9. Upon what principle does an electric generator operate?
10. Explain briefly the difference between a D.C. and a A.C. generator.